

Cooking System Comprising a Directly Heated Glass-Ceramic Plate

The invention relates to a cooking system based on the principle of heat conduction and is comprised of a one-piece cooking surface made of a glass-ceramic material and having at least one cooking zone, which can be individually directly heated by means of heating elements arranged on the underside of the glass-ceramic plate.

Cooking systems for cooking food consist of a cooking surface, arranged level, on which the cooking vessel is located. The heating arrangement is applied underneath the cooking surface, wherein various function principles of heat transmission are utilized. An optimally tuned cooking system has a level contact between the bottom of the pot and the cooking surface, so that the transmission of the contact heat can take place with as little loss as possible. In the heating state, all surfaces in contact with each other should be arranged in as plan-parallel a manner as possible. The temperature gradient between the heating element and the material to be cooked must be sufficiently great for making a rapid heating process possible. Heat losses to the surroundings should be minimized, which can be achieved by an appropriate insulation of the heating element. The heating element should be arranged at the least possible distance from the material to be cooked, i.e. directly underneath the cooking surface, while still meeting electrical standards.

In conventional systems with cooking plates made of cast iron, the heat is transferred in accordance with the principle of heat conduction. In this case the source of the heat consists of electrically insulated heating spirals made of resistance wire in the interior of the cooking plate. The individual cooking plates have been inserted into a mostly metallic

cooking surface. The cast iron cooking plate is arranged above the cooking surface and, because of thermal expansion, slides on the surface of the support plate during the cooking process. Thermal and mechanical uncoupling of the components is achieved in this way. Because of their high-mass construction, these systems are very sluggish in the way they behave during the pre-cooking process and in their controllability.

Further development of such cooking systems is achieved by a changed arrangement of the heating elements and a modification of the material of the cooking plate. In connection with this, thin ceramic disks of good heat conductivity and great mechanical stability, preferably made of non-oxidic ceramic materials, such as Si_3N_4 or SiC , are used as cooking plates. EP 0 853 444 A2 and EP 0 069 298 describe ceramic cooking systems on Si_3N_4 basis, which have good heat-conducting properties and are very flat. These known cooking plates are inserted into cooking surfaces, preferably of pre-stressed flat glass, but also stone plates or plates made of polymer-ceramic composite materials. To achieve heating of the entire cooking surface, but to counteract mechanical stresses, an expansion gap is provided between the ceramic plate and the cooking surface. The connection is made with the aid of heat-resistant adhesives. Electric heating takes place by means of layers, through which current flows and which adhere with a solid bond to the cooking plate. Thin layers, which are flat all over, are used, in particular made of SnO , as shown in USP 6,037,572. Metal foils are also used as heating elements and are pressed against the substrate, or are connected with the ceramic plate by heat-conducting temperature-resistant adhesives. An electrical insulation between the heating device and the cooking vessel which meets standards is assured by the ceramic plate itself. In connection with cooking plates made of

materials which are electrically conductive, such as SiC, for example, it is possible to install a ceramic insulating plate between the heating device and the cooking plate in order to assure electrical insulation. The described construction is distinguished in particular by improved output in the field of pre-cooking process output, efficiency and controllability. A temperature gradient during the pre-cooking process can be reduced by means of the direct contact between the heating element, the cooking plate and the bottom of the pot, and the high degree of heat conductivity of the ceramic plate, without reducing the pre-cooking process output. Heat losses are minimized, because of which the efficiency of the system is increased. Temperatures in the surface of the cooking zone are reduced to approximately 350°C. The structural height of the cooking plate is also reduced in comparison with cast iron cooking plates.

Alternatively to these systems, radiation-heated systems exist in the market. The cooking surfaces are made of a material of low heat conductivity and heat expansion, such as, for example, glass-ceramic plates, in particular glass-ceramic plates with components from the $\text{Li}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ system, also known by the name Ceran[®]. Radiation-heating elements are located underneath the one-piece flat cooking surfaces. A glowing resistance wire, made of metallic alloys and through which current flows, generates the heating energy. Heat transfer takes place by means of heat conduction and convection, however, with a proportion of approximately 40% by heat radiation. When using cooking utensils of lower quality, an air gap exists between the bottom of the pot and the cooking surface during the cooking operation, which reduces the transfer of contact heat. A drastic drop during the pre-cooking process output is counteracted by the combination of heat

radiation and heat conduction. The electrical insulation conforming to standards (EN 60335 and UL 858) between the heating elements and the cooking vessel wherein, when operated at 230 V ac, an electric strength of 3750 V and a leakage current of less than 0.25 mA must be provided during operation, is provided by an air gap. For achieving a sufficient pre-cooking output, the heating element temperature is set to values around 1100°C, so that the system on the cooking zone top has a maximum possible temperature of approximately 570°C. The advantage of such systems is their great esthetic appeal created by the appearance of the one-piece level cooking surface. A further advantage to be derived from this is the ease of cleaning, as well as the free design options by means of a surface decoration. Because of the lower-mass construction and the reduced heat capacity of the thin glass- ceramic plate, the controllability and the pre-cooking time is reduced in comparison with the cast iron cooking plate.

The ceramic cooking systems on the basis of SiN or SiC are distinguished primarily by high output data. Rapid pre- cooking times and effectiveness of more than 80% are achieved. However, the technical solution causes negative values regarding the esthetic aspects and the ease of cleaning. Cooking output is improved by the use of a cooking plate of high heat conductivity. However, so that heating is locally limited to the cooking zone, a heat barrier between the cooking zone and the remaining cooking surface must be achieved. For this purpose, the one-piece cooking plate is provided with bores, into which ceramic disks are glued. Moreover, the ceramic disks must protrude slightly above the plane of the cooking surface so that it is assured that in every case the bottom of the pot rests on the ceramic cooking zone and no air gap is created in the direction of the heating surface.

Furthermore, an expansion gap, filled with adhesive, is provided. Because of this, the haptical properties of the cooking surface are inhomogeneous and the ease of cleaning is reduced. A cooking zone soiled with food can be cleaned only tediously by mechanical tools, such as sponges or scrapers, because of the protruding ceramic disks and the expansion gap. The ceramic cooking zone differs in color from the remainder of the cooking surface, the appearance comes close to the cooking field made of grey cast iron. Thus, the design of the cooking surface become less attractive.

Radiation-heated glass-ceramic cooking fields are built in one piece and therefore have a high degree of a pleasing visual appearance and ease of cleaning. No interfering edges and gaps exist. The output of such cooking systems in view of pre-cooking, efficiency and controllability must be negatively valued in comparison to Si_3N_4 cooking systems. Because at temperatures starting at 250°C , the glass-ceramic plates become electrically conducting, the heating element must be mounted a defined distance away from the cooking surface in order to achieve the required electric strength of 3750 V. The pre-cooking behavior and controllability are worsened by the air gap between the heating device and the cooking surface. It is necessary to generate high temperatures of more than 1100°C in the heat conductor for achieving a sufficient pre-cooking output. Since the surroundings of the cooking zone are also heated by the heating element, heat losses are created, and the efficiency of the cooking system drops in comparison with ceramic SiN cooking systems from approximately 80% to 60%. The construction with an air gap creates a minimum structural height, which limits the built-in options in a cooking trough. The number of

components of a cooking trough with heating elements, including their fixation in place and a control device, is large.

The construction of an optimized cooking system with a one-piece, visually pleasing cooking surface and improved output data becomes possible by means of the direct heating of a glass-ceramic cooking surface.

EP 0 861 014 A1 describes a cooking plate wherein a glass-ceramic plate is heated by means of metallic conductors directly printed onto it. The electrical insulating layer between the glass-ceramic plate and the heating element, which for meeting standards is absolutely necessary, is not mentioned there.

EP 0 866 641 A2 solves the problem with a compromise wherein a one-piece glass-ceramic plate is being used and, as with the Si_3N_4 system, heating takes place by means of heating elements directly applied to the underside. The technical conversion is accomplished by pressing or gluing on a metal foil, which is then electrically heated. The low maximum cooking temperature which can be achieved by this is disadvantageous here. In tests of our own it has been found that simply pressing on a foil heating element causes a strong reduction of the pre-cooking output. A chemical bond or at least a flat mechanical tooth connection is necessary. All commercial adhesives having good heat conduction do not permit their use at temperatures greater than 350°C . However, temperatures around 550°C , measured at the heating element, are required for achieving a pre-cooking output in connection with a glass-ceramic substrate with direct heating, which is required for the rapid frying of food. The reason for this is the low heat conductivity of glass-ceramic materials (1 to 2 W/mK) in comparison with SiN ceramic cooking plate (20 to 30 W/mK). With

ceramic cooking systems, the temperature at the heating element is approximately 400°C. When using glass-ceramic plates as cooking plates, temperatures around 550°C are necessary for achieving an equivalent output. A further problem is the different thermal expansion of glass-ceramic material (approximately 0 to $1.5 \times 10^{-6}/\text{K}$) and metal heating elements (greater than $10 \times 10^{-6}/\text{K}$). No adhesive, which is stable up to 550°C and has good heat conduction with sufficient ductility for compensating heat expansion can be technically realized.

In accordance with one construction, a solid bond between the heating element and the insulated glass-ceramic substrate takes place in that an electrical insulating layer is located between the glass-ceramic plate and the heating elements applied in the form of a layer. It preferably consists of electrically highly-insulating ceramic materials from the material system $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-MgO}$ (corundum, quartz, cordierite, mullite). WO 00/15005 describes possibilities for depositing the insulating layer on the low-expanding substrates. Even if the layer bond is mechanically stable, the basic problem still exists that an arching of the cooking zone occurs when heating the cooking system. This is created by the different expansion of the glass-ceramic plate and the insulating layer or heating layer (comparable to a bi-metal effect). The air gap being created between the bottom of the pot and the top of the cooking plate lessens the contact surface and considerably reduces the heat transfer. Pre-cooking times worsen dramatically.

EP 0 951 202 A2 describes a directly heatable cooking system with a metallic interlayer, which is grounded for meeting the electrical standard. In this way, occurring excess voltages or leakage currents are drained off. However, the structure of such a system is technically difficult to realize and uneconomical.

It is the object of the invention to create an electrically directly heatable cooking system of the type mentioned at the outset, which is, along with a visually pleasing appearance, easy to clean. The system output is intended to be improved over conventional cooking systems with heating by way of radiating elements. The cooking plate is intended to contain heating zones for the cooking operation, which are individual for the segments, and to assure a plan-parallel arrangement of the bottoms of pots and the cooking plate during cooking operations at temperatures up to 500°C.

In accordance with the invention, this object is attained in that the glass-ceramic plate with main crystalline phases of the high quartz mixed crystal or keatite mixed crystal types, mainly constituted of the components $\text{LiO}_2\text{-Al}_2\text{O}_3\text{-SiO}_2$, with a coefficient of expansion of $\alpha = 0$ to $1.8 \times 10^{-6}/\text{K}$, preferably of $\alpha = 0$ to $1.5 \times 10^{-6}/\text{K}$, and a heat conductivity of $< 3 \text{ W/mK}$, preferably $< 2.7 \text{ W/mK}$, has on the underside at least one cooking zone, that the heating elements of the cooking zone consist of metallic layers, and that between the underside of the glass-ceramic plate a porous ceramic layer is arranged as the electrical insulating layer.

In this embodiment the cooking surface is of one piece in accordance with the requirements. Cooking zones can be distributed on the underside of the glass-ceramic plate by means of the applied heating elements, which can be operated at different temperatures. The low heat conduction capability of the glass-ceramic plate must be selected so that the heating of the entire cooking surface because of transverse heat conduct is prevented. The glass-ceramic plate must furthermore have a low thermal expansion, so that no or only small heat stresses are created in the course of the temperature changes, which could leave to the

breakage of the glass-ceramic plate. All this is guaranteed by means of the materials used for the glass-ceramic plate.

The layer bond between the heating elements and the underside of the glass-ceramic plate at cooking temperatures of up to 500°C at the top of the glass-ceramic plate must meet the prescribed standards. If the glass-ceramic plate is electrically conductive, a ceramic layer of Al_2O_3 , mullite, cordierite, circonium silicate or $\text{SiO}_2/\text{TiO}_2$ is used for electrical insulation between the underside of the glass-ceramic plate and the heating elements.

In accordance with one embodiment, the selection of the material and the method for applying the heating elements is provided in such a way that the heating elements are applied by thermal spray methods, in particular atmospheric plasma spray methods, cold gas spray methods, of NiCr base alloys, NiAl base alloys, CrFeAl base alloys or oxidation-resistant cermets, such as Cr_3C_2 -NiCr or WC-CoCr, or that the heating elements are applied by means of screen-printing methods from Ag/Pd-containing pastes with a glass frit.

So that the layer adhesion during temperature changes in the course of the heating process remains stable, but the occurrence of high thermal tensions in the material is prevented, it is provided in accordance with a further embodiment that the insulating layer is bonded to the underside of the glass-ceramic plate by means of thin strips of primary ceramic particles of a width of approximately 50 to 150 nm.

For a reduction of heat losses it can be additionally provided that the heating elements are covered by means of a thermal insulating layer of silicate fiber materials.

The required properties of the cooking system are maintained if the glass-ceramic plate has a specific resistance $> 10^5 \Omega$, and the entire cooking system has a breakdown resistance of $> 3750 \text{ V}$, while in accordance with the Standard 60335-1 the leakage current is $< 0.25 \text{ mA}$ per cooking zone.

The invention will be described in greater detail by means of an exemplary embodiment represented in the drawings. Shown are in:

Fig. 1, a sectional view of a cooking system consisting of a glass-ceramic plate, ceramic layer, heating elements and thermal protection layer, and

Fig. 2, an enlarged partial sectional view in the bonding area between the glass-ceramic plate and the ceramic plate as the electrical insulating layer.

A cooking system in accordance with the invention is shown in Fig. 1. With its top, the glass-ceramic plate 10 constitutes the cooking surface. A ceramic plate 20, which can be provided with nubs for increasing the surface with the glass-ceramic plate 10, has been applied to the underside of the glass-ceramic plate for electrical insulation. The layer thicknesses lie between 50 and 350 μm , in particular in the range between 160 to 200 μm . The insulating layer, i.e. the ceramic plate 20, supports the heating elements 30 which define the cooking zones and which can be individually heated and controlled.

The heating elements can be embodied in the form of strip conductors or flat heating elements.

The material of the glass-ceramic plate has a heat conductivity $< 3 \text{ W/mK}$, in particular $< 2.7 \text{ W/mK}$, and a coefficient of expansion $\alpha = 0$ to $1.8 \times 10^{-6}/\text{K}$, in particular $\alpha = 0$ to $1.5 \times 10^{-6}/\text{K}$. The materials have main crystalline phases of the high quartz mixed

crystal or keatite mixed crystals type, mainly constituted of the components LiO_2 - Al_2O_3 - SiO_2 . The electrical insulation between the underside 2 of the glass-ceramic plate 10 and the ceramic layer 20 is provided by a layer of a highly insulating ceramic material.

In this connection, materials such as Al_2O_3 , mullite, cordierite, circonium silicate and SO_2/TiO_2 alloys have proven themselves. However, these materials show a large thermal expansion with values of $\sigma > 3 \times 10^{-6}/\text{K}$. So that the bonded layer of the glass-ceramic plate 10 and the insulating layer 20 is stable during heating operations, it is necessary, besides good layer adhesion, to simultaneously avoid the appearance of high heat stresses. This is assured by means of a mechanism based on a chemical adhesion mechanism between the ceramic layer 20 and the glass-ceramic plate 10 and a defined porosity of the ceramic layer material. Young's modulus of the layer is lowered by the porosity, the layers become quasi-ductile.

Tests have also shown that the insulating layer 20 does not adhere flat to the underside of the glass-ceramic layer 10. Thin strips of ceramic particles of widths of approximately 50 to 150 nm are formed in the interface, which, as can be seen, are responsible for the connection shown by the reference numeral 21 in the enlarged partial sectional view in accordance with Fig. 2. There is no contact between the glass-ceramic material and the insulation in the area of the pores 22. This bond, which is not flat, reduces the inherent tensions in the system. Delamination of the bonded layer during cooking operations is prevented by this mechanism. Moreover, arching of the glass-ceramic plate 10 in the area of a cooking zone is minimized by the greater expansion of the insulating layer

20, so that values < 0.2 mm are achieved over the diagonal extension of the cooking zone. It is possible by means of this to achieve a great cooking performance of the cooking system.

The heating elements 30 can be applied by means of screen printing or thermal spraying, in particular atmospheric plasma spray methods or cold gas spray methods. With the screen printing method, the heating elements preferably consist of Ag/Pd-containing pastes with glass frits or, in the case of thermal spray methods, of NiCr base alloys, NiAl base alloys, CrFeAl base alloys or oxidation-resistant cermets, such as Cr_3C_2 -NiCr or WC-CoCr.

The chemical bonding of the ceramic layer 20 is created by particle diffusion in the interface ceramic/glass-ceramic material in the area of the strips. In the course of our own tests it was surprisingly found that alone the use of glass-ceramic materials with main crystalline phases of the high quartz mixed crystal type of the components LiO_2 - Al_2O_3 - SiO_2 , also called LAS glass-ceramic materials, and known under the name Ceran, makes possible the described required chemical bonding to the ceramic layer 20. The cause is the chemical relationship between the glass-ceramic material and the insulating materials. The latter mainly consist of the compositions of SiO_2 and Al_2O_3 with additions of MgO and TiO_2 . A boundary surface diffusion takes place during chemical bonding. An exchange of the elements occurs from the side of the glass-ceramic material, as well as the ceramic side. With other material pairings a reaction layer is created in the glass-ceramic material in the interface during diffusion, which has an increased thermal coefficient of expansion. Microscopic tears are formed by the induced stresses, which lead to a lowering of the shock resistance of the total system down to values below the standard requirements. Poor bonding

of the layers and a resultant delamination during heating can be observed. In the case of using glass-ceramic materials with higher thermal coefficients of expansion, the described positive effect also occurred. In contrast to LAS glass-ceramic materials, the main crystalline phase is constituted as keatite mixed crystals, because of which the thermal coefficient of expansion, inter alia, is increased to approximately $\alpha = 1.5 \times 10^{-6}/K$. In this way the expansion difference with the ceramic layer 20 is minimized.

Thus, a glass-ceramic plate 10 as the cooking surface for the described cooking system combines the one-piece surface of a highly pleasing visual appearance and ease of cleaning with a possibility of the direct application of a permanently durable layer system for heating. The provision of high heating output with a simultaneously existing flatness of the cooking zones causes a considerable increase of the cooking output in comparison with conventional cooking systems.